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Eight element circular array of circular patch microstrip antenna in dielectric medium

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Abstract The theoretical analysis of eight element circular array of circular patch microstrip antenna is proposed for X-band in plasma medium The far-zone field patterns are obtained using vector wave function approach and analytical technique of microstrip antennas. The field patterns are plotted for both freespace and plasma modes. Other antenna parameters like half power beam width (HPBW), radiation conductance and directive gain are also computed The results are used for the design of phased array antenna system in mobile communication systems.

Keywords . Microstrip antenna, plasma medium, radiation properties

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Almost complete control of beam scanning, pattern shape and polarization can be obtained from a phased array microstrip antennas. Such an antenna is useful for many radar and communications systems. Circular array is best suited for phase scanning by ferrite phase shifters [1,2], because of easy approach to change the progressive phase between the elements. The phase shift is controlled by the magnetic field within the ferrite, which in turn, is controlled by the amount of current flowing through the wires wrapped around the phase shifter [3]. In present communication, an eight element circular array of circular patch microstrip antenna is investigated for phased array applications. The properties like field patterns, radiation conductance, HPBW and directive gain are computed and analysed in X-band.

The configuration and co-ordinate system of circular array of circular patch antenna (CPCPA) is given in Figure 1. It consists of eight identical elements on a dielectric substrate of thickness h and substrate permittivity ε_r of 3.54 value at 10 GHz placed in x-y plane along a circular ring of radius ρ. The radius of each element is a. The array elements are taken from point M which moves such that it occupies uniform angular distance ($\phi = \pi/4$) between all the eight elements from x-axis. Each patch can be excited by a

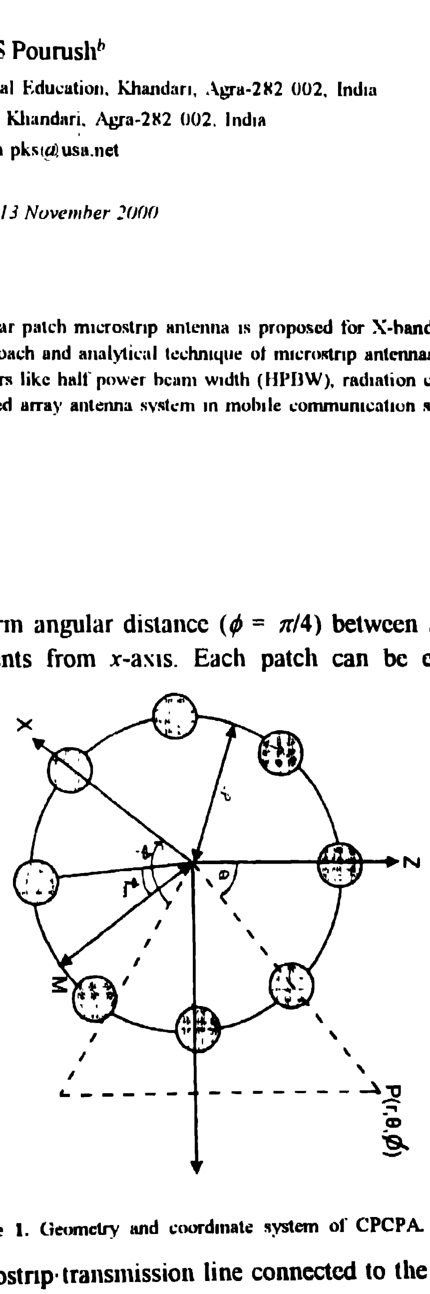

Figure 1. Geometry and coordinate system of CPCPA.

microstrip transmission line connected to the edge or by a coaxial line from the back at the plane $\phi = 0$. For 8-element

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circular array, the array factor is obtained using the relation given by [4]

$$AF(\theta,\phi) = \sum_{m=1}^{8} \gamma_0 \exp[j\{\beta_e \rho \sin\theta \cos(\phi - \phi_m)\} + \beta_1\}].$$

Following Balanis [5] and neglecting coupling between elements [6], the far zone expressions for CPCPA are obtained as follows .

EM-mode :

$$E_{\theta t} = -j^n V_0 a \beta_e \gamma_0 \left(\exp(-j\beta_e r)/2r\right)\cos n\phi . J_n(\beta_e a \sin\theta)] \times\left[\sum_{m=1}^{8} \exp j\{\beta_e \rho \sin\theta \cos(\phi - \phi_m)\} + \beta_1\}\right]. \quad (1)$$

Similarly

$$E_{\phi t} = j^n V_0 a \beta_e \gamma_0 \left(\exp(-j\beta_e r)/2r\right)\cos\theta . \{J_n(\beta_e a \sin\theta)/(\beta_e a \sin\theta)\}\sin n\phi] \times\left[\sum_{m=1}^{8} \exp j\{\beta_e \rho \sin\theta \cos(\phi - \phi_m)\} + \beta_1\}\right]. \quad (2)$$

In plasma mode :

$$E_{pt} = (-j)^{n+2}\{60\pi(1-A^2)C'/AV\}\gamma_0 K_1^2 n J_n(K_1 a) \exp(-j\beta_p r)/r\}\{\sin(\beta_p h\cos\theta)/\beta_p h\cos\theta\} \times J_n(\beta_p a \sin\theta)\sin(n\phi) \times\sum_{m=1}^{8} \exp[\{\beta_p \rho \sin\theta \cos(\phi - \phi_m)\} + \beta]. \quad (3)$$

The total field pattern $R(\theta,\phi)$ is obtained as

$$R(\theta,\phi) = |E_{\theta t}|^2 + |E_{\phi t}|^2 . \quad (4)$$

The radiated power in EM-mode is obtained by integrating the Poynting vector over a large sphere and is obtained as

$$P_e = \{(\beta_e a)^2 V_0^2 / 960\pi)\} / I_1 ,$$

where

$$I_1 = \int_0^{2\pi}\int_0^{\pi}\left[\{J_n'(\beta_e a \sin\theta)\cos n\phi\}^2 + \{\{J_n(\beta_e a \sin\theta)/\beta_e a \sin\theta\}\sin n\phi \cos\phi\}^2\right] \times\left[\sum_{m=1}^{8} \exp j\{\beta_e \rho \sin\theta \cos(\phi - \phi_m) + \beta_1\}\right]^2 \times \sin\theta d\theta d\phi . \quad (5)$$

The radiation conductance G_e in the EM mode is given by

$$G_e = 2P_e / V_0^2 = \{2(\beta_e a)^2 / 960\pi\} I_1 . \quad (6)$$

The directive gain of CPCPA in a given direction is defined as

$$D_g = 4\pi M_e \Big/ \int_0^{2\pi}\int_0^{\pi} M_e \sin\theta d\theta d\phi \quad \text{.. ...for } \theta = \pi/4,\ \phi = 0, \quad (7)$$

where

$$M_e = \left[\{J_n'(\beta_e a \sin\theta)\cos n\phi\}^2 + \{(J_n(\beta_e a \sin\theta)/\beta_e a \sin\theta)\sin n\phi \cos\phi\}^2\right] \times\left[\sum_{m=1}^{8} \exp j\{\beta_e \rho \sin\theta \cos(\phi - \phi_m) + \beta_1\}\right]^2 . \quad (8)$$

The values of $R(\theta,\phi)$ are computed using input data of fr = 10 GHz, a = 0.467 cm, ρ = 3.18 cm, ε_r = 3.54, n = 1 and $\beta_1 = \pi/2$ for E-plane and H-plane. The values of ϕ_m are chosen such that it has uniform and finite phase difference between the consecutive elements, *i.e.*, ϕ_1, ϕ_2, ϕ_3, ϕ_4, ϕ_5, ϕ_6, ϕ_7 and ϕ_8 have values $\pi/4$, $\pi/2$, $3\pi/4$, π, $5\pi/4$, $3\pi/2$, $7\pi/4$ and 2π respectively from x-axis. The results thus obtained are plotted for A = 0.5 (plasma) and A = 1 (free space) for E and H plane in Figures 2 and 3 respectively. The HPBW is reported in Table 1 The plasma fields are computed for

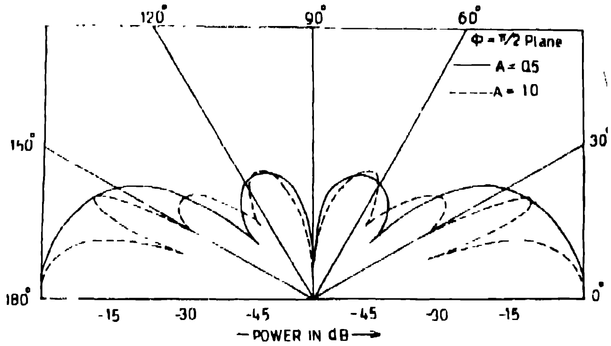

Figure 2. E-plane field pattern of CPCPA in free space and plasma

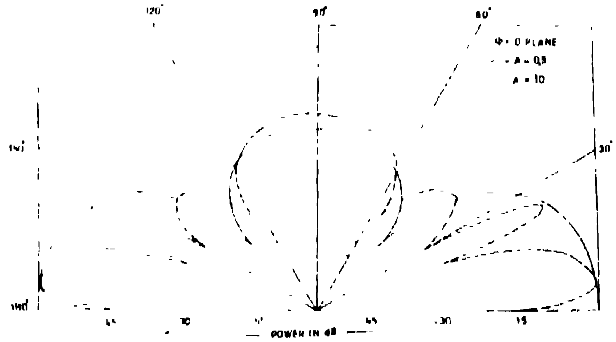

Figure 3. H-plane field pattern of CPCPA in free space and plasma

Table 1. Measured values of HPBW of CPCPA in plasma and free space

Plane	HPBW	
	Free space (A = 1)	Plasma (A = 0.5)
E-plane	10°	20°
H-plane	20°	36°

A = 0.5 in E-plane at θ = 0.5° increments in a small interval of 10. Assuming that there is no lobe narrower than 0.5, the normalised values of the P-mode field patterns are plotted between θ = 50° to 60° in Figure 4. It is found that the plasma mode field patterns are oscillatory in nature. The plasma medium effects the radiation properties of the array antenna to a great extent. From Figures 2 and 3, it is obvious that the presence of plasma modifies the radiation field patterns significantly. Considerable redistribution of the field

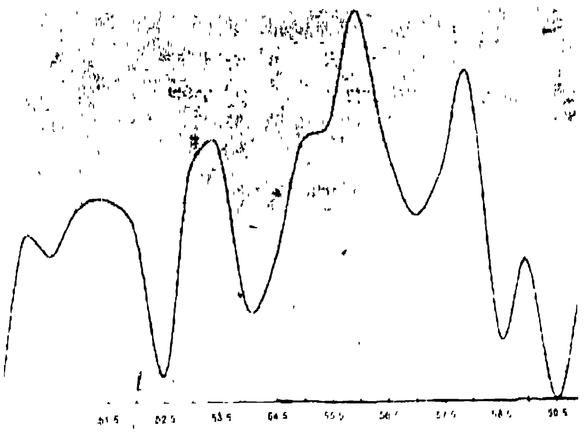

Figure 4. *P*-mode field pattern of CPCPA

intensities are observed. In *E*-plane, there is change in the symmetry of the patterns and the maxima is unchanged. In *H*-plane the same type of changes are observed except there is a minima at 90°. The number of lobes is also reduced in presence of plasma. The HPBW also increases in plasma as the number of lobes is decreased in plasma as reported in Table 1. In Table 2, the change in radiation conductance and directive gain is given. It is observed that the directive gain and conductance decrease with increase in plasma parameter. The table also presents the directive gain and conductance of a single patch circular microstrip antenna, which is very less in comparison to that of an array.

Table 2. Calculated values of radiation conductance and directive gain of CPCPA in plasma and free space

Characteristics	Free space ($A = 1$)		Plasma ($A = 0.5$)	
calculated	Single patch	Array	Single patch	Array
Radiation conductance (10^{-3} mho's)	2.2568	7.7725	1.3634	5.3286
Directive gain (dB)	1.46		1.29	3.19

Finally, it is concluded that this study is useful for space vehicles because such type of array can be mounted on-board space vehicles with both flat and curved surfaces. This geometry is easy to handle for phased array applications of microstrip antennas.

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